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# PHYSICS RESEARCH IN CATALONIA: THE HIGHLY CITED PAPERS*

## Introduction

Very often, the knowledge that lay people and specialists have about scientific research in Catalonia is just an amount of generic data about the budget (input) for a certain period, and some undefined statistical figures on the number of publications (output). Thus it is imperative that researchers as well as politicians and society in general have a solid knowledge of these matters in order to more effectively situate research in our innovative, cultural and entrepreneurial panorama.

In the overall Spanish context, there are a few references to previous bibliometric approaches in Physics (J.R. Pérez, 1991). However, these have serious data restrictions and the time that has passed since they were published is an indicator of the urgent need for new studies in this field.

The aim of this paper is to present a first approach to the papers most frequently cited in the discipline of physics ever published by researchers at Catalan universities and by Catalan researchers working abroad. The main source of this work is the *Report on Physics research in Catalonia 1990-1995* by Professor David Jou in the framework of the programme of reports started by the IEC and supported by the CIRIT. In that report, a list of papers cited over one hundred times was presented. Thus, we thought it worthwhile (encouraged by the author of the report) to enlarge and extend that original approach. One result has been to double the number of referenced highly cited papers on the list of the report, which certainly refines and improves our point of view about this issue.

The analysis of highly cited papers is not just anecdotic. In 1995, W. Glänzel found that the indicators based on the most cited papers in Physics yielded valuable information in addition to other national or regional bibliometric analyses (usually based on the citation mean). Certainly, the most cited scientific papers agglutinate a high percentage of the total amount of citation addressed to whole papers population. They also point out the *hottest* scientific areas or lines.

This accumulative effect is well known in bibliometry and has also been demonstrated in our work on Physics in Catalonia as we develop below. As an example, the year 1982 saw the publication of only in 2 papers (see Table 1) 40% of the total citation of the total papers population. Thus, knowledge of the number of most cited papers is necessary for an accurate interpretation of the global data. If it was based on mean values the results would show serious deviation.

## Objectives and method

General data on research funds in Spain, and, specifically on Catalonia, show an important growth stage between 1980 and 1992, when the R&D expenditure/ PIB nearly duplicates, this is followed after 1992 by a steady state step due to budgetary restrictions regarding the application of the Maastricht Treaty requirements for entry into the single currency, the Euro. This stagnation has left the expenditure ratio and number of researchers per 1000 inhabitants still lower than the European average.

Concerning the output, expressed as number of scientific publications, it is clear that there is an important improvement in the number of papers and in their average impact. This is measured by the number of cites per paper or, for journals, by the impact factor or cites per paper in the last two years following their publication. This will be studied in a future work (There are other indicators such as patents or technology transfer not considered in this survey,). When we question the real impact of these papers, it is interesting to focus on the most cited papers or books ever published from Catalan universities as well as the ones coming from abroad but with Catalan authors working at foreign R&D centres. This allows us to see a complete image and to realise how the negative flow of researchers from the country impacts on several episodes of our recent history.

It is thought that while the number of researchers, publications, and productivity per researcher has increased, there is still a long way to go before Catalonia can enter into the highest range of scientific production. We are referring to papers published in high impact journals such as *Physical Review Letters, Nature* or *Science*, for example, on the publication of long reviews in influential journals-*Reviews of Modern Physics, Physics Reports, Reports on Progress in Physics-;* publication of monographic issues in widely distributed collections, or publication of special papers resulting very known at international level that have achieved a big amount of citations.

Another limitation of Catalan physics is the lack of large facilities. This point affects negatively the international representation in two ways: in the number of projects and in the number of papers and their impact. As an example of a long established institution considering the average impact we might consider the research produced by two NASA mis-

* Pau Senra, Universitat Pompeu Fabra. Lluís Rovira, Comissió Interdepartamental de Recerca i Innovació Tecnològica (CIRIT).

Table 1. List of articles cited more than 100 times in which the address of at least one author is a Catalan research institution.

*Analytical and numerical studies of multiplicative noise* Sancho-JM Gunton-JD Katz-SL Miguel-MS
SANCHO-JM-1982-PHYS-REV-A-V26-P1589 290(2,10,21,23,18,21,40,34,22,14,12,23,11,10,11,7,8,3)

*An Experimental Method for the Observation of R.F. Transitions and Laser...* Gozzini-A Moi-L Orriols-G ALZETTA-G-1976-NUOVO-CIMENTO-B-V36-5 280(0,0,0,5,3,3,7,1,2,7,4,5,7,4,11,11,30,13,16,29,27,35,34,27)

*Parton distributions from a global qcd analysis of deep inelastic–...* Laboratoris d'altes energies de la UAB
MORFIN-JG-1991-Z-PHYS-C-V52-P13 242(0,32,81,56,27,20,11,12,3)

*Sum rules for nuclear collective excitations.* Bohigas-O Martorell-J
BOHIGAS-O-1979-PHYS-REP-V51-P267241(3,18,21,15,21,11,10,14,11,12,9,21,8,7,10,14,4,6,10,11,5)

*Determination of the number of light neutrino species.*Group1
DECAMP-D-1989-PHYS-LETT-B-V231-P519 230(1,96,66,29,11,7,4,10,2,1,3)

*Non-absorbing atomic coherences by coherent 2-photon transitions in a 3-level...*Arimondo-E Orriols-G
ARIMONDO-E-1976-LET-NUOVO-CIMENT-V17-P333218(1,0,0,2,2,3,6,2,1,8,7,5,7,7,15,18,13,11,17,23,21,16,23,10)

*Searches for new particles in Z decays using ALEPH detector.*Group2
DECAMP-D-1992-PHYS-REP-V216-P253 218(5,0,0,33,33,41,44,35,16,11)

*Extended irreversible thermodynamies.*Jou-D Casasvazquez-J Lebon-G
JOU-D-1988-REPORTS-PROG-PHYS– V51-P1105 210(0,11,18,25,19,38,20,35,17,19,17,10)

*Extended irreversible thermodynamies.*Jou-D Casasvazquez-J Lebon-G
JOU-D-1993-1996-SPRINGER-VERLAG 206(2,7,33,31,37,57,39)

*Dynamical scaling of structure-function in quenched binary-alloys.*Lebowitz-JL Kalos-MH Marro-J
LEBOWITZ-JL-1982-ACTA-METALL-V30-P297 201(3,15,22,16,13,12,16,13,8,14,12,10,8,9,12,7,6,5)

*A vector meson dominance aproach to scale invariance.*Bramón-A Etim-E Greco-M
BRAMÓN-A-1972-PHYS-LET-B-V41-P609 183(0,14,30,21,14,14,10,9,8,14,6,11,9,4,4,4,4,3,0,0,0,2,0,00,1,0,1)

*Quantum energy-gap in 2 quasi-one-dimensional s#1 heisenberg antiferromagnets* Verdaguer-M et alt.
RENARD-JP-1988-J-APPL-PHYS-V63-P3538 181(0,7,12,23,33,16,34,24,11,10,8,3)

*Observation of Two-Dimensional Spatial Solitary Waves...* Torner-Ll, Menyuk-CR, David-J,
TORRUELLAS-WE– 1995-PHYS-REV-LETT-V74-P5036 179(6,16,65,63,29)

*Chiral lagrangians for massive spin-1 fields*Ecker-G Derafael-E Gasser-J Leutwyler-H Pich-A
ECKER-G-1989-PHYS-LETT-B-V223-P425 160(0,12,16,14,23,11,20,26,22,9,7)

*Density functional calculation of stopping power of an electron-gas for slow ions* Nieminen-RM et alt
ECHENIQUE-PM-1981-SOLID-STATE-COMMU-V37-P779 157(2,3,4,2,6,5,7,9,8,10,10,14,10,12,17,8,13,16,1)

*Nonabsorption Resonances by Nonlimear Coherent Affects in a Three-Level System.*
ORRIOLS-G-1979-NUOVO-CIMENTO-B-V53-P1 154(1,1,6,9,5,7,15,8,5,7,5,10,8,11,10,8,11,11,11,9,6)

*Neutrino mass and baryon-number nonconservation in superstring models* Mohapatra-R Valle-J
MOHAPATRA-RN-1986-PHYS-REV-D-V34-P3457154(0,14,11,4,10,8,10,5,5,12,10,13,42,10)

*QCD sum rules in the effective heavy quark theory*.Bagan-E Ball-P Braun-VM Dosch-HG
BAGAN-E-1992-PHYS-LETT-B-V278-P457 144(7,21,28,23,26,20,11,8)

*The Pole Mass in Perturbative QCD.*
TARRACH-R-1981-NUCL-PHYS-B-V183-P384 138(2,12,6,7,5,1,1,3,6,3,6,8,5,12,17,12,15,8,9)

*A precise determination of the number of families with light neutrinos and of the z boson...* Group1
DECAMP-D-1990-PHYS-LETT-B-V235-P399 129(62,43,11,5,2,1,4,0,1,0)

*The self-couplings of vector bosons: does LEP-1 ...*Derujula-A Gavela-MB Hernandez-P Masso-E
DERUJULA-A-1992-NUCL-PHYS-B-V384-P3 134(0,21,30,26,21,16,13,7)

*QCD – Renormalization for the Practitioner*Pascual-P Tarrach-R
PASCUAL-P-1984-QCD-RENORMALITZATION 119(0,2,10,7,10,12,5,8,6,15,6,9,14,5,7,3)

*An extension of the local equilibrium hypothesis.*Lebon-G Casasvazquez-J Jou-D
LEBON-G-1980-J-PHYS-A-V13-P275 112(11,6,14,11,7,11,8,5,9,6,4,3,5,4,2,3,1,1,0,1)

*Zeta-Function Regularization is uniquely defined well*
ELIZALDE-E-1994-ZETA-REGULARIZATION 111(6,8,28,19,30,20)

*Nonabsorption hyperfine resonances in a sodium vapour irradiated by a multimode...*Moi-L Orriols-G
ALZETTA-G-1979-NUOVO-CIMIENTO-B-V52-P209 104(1,1,1,6,3,1,8,6,3,6,5,5,7,8,7,6,7,6,8,2)

*Thermodynamic analysis of thermal measurements in thermoelastic martensitic...*Planes-A
ORTIN-J-1988-ACTA-METALL-V36-P1837 100(2,9,6,7,13,13,8,9,15,3,9,6)

*The dynamics of first-order phase transitions, a Phase Transitions and critical phenomena.*San Miguel.
GUNTON-JD-1983-PHASE-TRANSITIONS-CR-V8-P269 100(0,2,4,2,5,12,4,9,6,3,4,8,11,7,10,6,7)

*Superstring-inspired models.* Delaguila-F Blair-G Daniel-M Ross-GG
DELAGUILA-F-1986-NUCL-PHYS-B-V272-P413 97(3,31,18,7,13,11,2,1,2,3,5,0,0,1)

*Solitary waves due to x(2) :x(2) cascading.* Torner-Ll, Schiek-R
MENYUK-CR-1994-J-OPT-SOC– AM-B-V11-P2434 95(4,10,13,32,21,19)

*Electronic energy transfer induced by collision between two....*Alzetta-G Kopystynska-A Moi-L OrriolsG
ALLEGRINI-M-1976-OPT-COMMUN-V19-P96 90(0,3,6,2,7,9,6,7,2,5,7,3,4,3,4,3,5,1,2,2,1,4,3,1)

*The QCD Effective Action At Long Distances*Espriu-D Derafael-E Taron-J
ESPRIU-D-1990-NUCL-PHYS-B-V345-P22 89(1,13,15,11,18,9,9,7,6,0)

sions: COBE (searching for thermic radiation of the Big Bang) and CGRO (*Compton Gamma-Ray Observatory*). These started a research line for high energy sources in the Universe. Both missions 'launched' NASA between 1993 and 1995 in to the 'pole position' of impact among astronomy and astrophysics institutions (counting a minimum threshold of 30 papers) with 2521 cites (*Mitton, 1996*).

We have tried to obtain all available information concerning high impact papers (*hot papers*) to find out whether the idea of a respectable medium level Physics but publishing a few papers quite influential, is admissible or not. Impact has been calculated from citation indexed in SCI (*Science Citation Index*) by ISI (*Institute of Scientific Information)*. This database manages citation of scientific papers but excludes books and congress abstracts, which indicates that the total number of cites could reach higher values other than those given in SCI. To attain comparative standard results we have limited our study to SCI data, not considering other database such as SPIERS, used especially in high energy physics, which includes cites in congress abstracts and *preprints*.

Research of papers published with authors from Catalan universities since 1980, has been quite exhaustive and systematic. On the other hand, older papers or papers published by Catalan researchers abroad have been not so systematically covered since the main sources were the comments of several members of the scientific community. Another important source, showing a growing scope, is the on-line database for *Catalan Researchers abroad*, elaborated by CIRIT. This includes 130 Catalan researchers working in a wide variety of disciplines at foreign institutions (www.gencat.es/cur/catalans.htm).

Obtaining this kind of data is a difficult task. We are fully cognizant of the fact that our results are not complete and hope to apply to readers who may know of papers suitable for inclusion in this list and who are interested in contacting us. In this way we will be able to draw a more defined image of current physics. Hopefull, this will prove useful for public administrations as well as for people of different disciplines.

We have restricted the scope of the study to papers cited over 100 times. We are concerned that there may be scientific publications of high value below this threshold since some areas are rather small with a low number of putative papers cited. Some papers published in recent years in the temporal series may require more time to become cited.

Some references define highly cited papers as the ones cited over 10 times the average of citation of that subfield. Other authors regard the number of cites of a paper as related to the impact factor of the journal (W. Glänzel, 1995). Obviously, the number of cites has to be used carefully. Fluctuations observed among different disciplines (underestimation of several disciplines through citation could occur). This depends on fashions, efforts of authors to disseminate their results (and the charismatic position of the author), and other factors. On factor is negative citation (papers cited because contain important error or mistakes that stimulate discussion). Another common factor causing low citation of papers is the division of results in several papers. Certainly, this situation is one strategy to respond to the quick progress made in some scientific fields by publishing fragmented results immediately, avoiding reviews or the higher impact of big compilations.

Bibliometric citation analysis shows rather clearly the qualitative situation for one scientific field and the evaluation panels of experts (*peer review)* in the condensed matter subdiscipline (Rinia, 1998). This is so partly because there is a significant correlation between bibliometric indicators, especially citation, this result is not reached when the journal impact factor is used for papers from programmes evaluated by peer review nor when (in spite of basic research) we analyse applied research.

## Results and discussion

We have collected over 50 papers, half of them with at least one Catalan university including the author's address. A part of these papers have been developed abroad in research stays as shown in Table 1. The rest are the work of Catalan researchers residing permanently abroad and are presented in Table 2. Tracking down these papers is a rather complicated undertaking especially in the publications where they do not appear as first author.

## Journal analysis

Journals where the papers have been published are presented in Table 3. The second column refers to the number of papers published under a Catalan institution's address

Table 2. List of articles cited more than 100 times in which at least one of the authors is Catalan and in which no Catalan research institution is mentioned.

*Modulation Spectroscopy* CARDONA-M-1969-MODULATION-SPECTROSC-P117
705(10,5,25,35,35,21,31,28,26,24,18,22,16,13,17,20,28,20,27,22,16,27,25,22,21, 27,30,22,26,30,16)

*Electroreflectance at a semiconductor– Electrolyte Interface* CARDONA-M-1967-PHYS-REV-V154-P696
629(12,46,47,45,36,35,39,24,25,12,19,7,12,21,19,15,19,15,19,14,22,14,21,12,18,9,10,12,16,4,13,3,4)

*Characterization of chaotic quantum spectra and universality of Level...*Giannoni-MJ Schmit-C
BOHIGAS-O-1984-PHYS-REV-LETT-V52-P1 524(10,13,27,25,28,25,34,40,47,38,34,36,43,60,36,28)

*Optical properties of silver and cuprous Halides* CARDONA-M-1963-PHYS-REV-V129-P69
394(4,5,11,9,10,13,4,13,19,15,20,14,6,12,14,7,20,16,9,11,13,10,10,12,11,19,6,7,5,5,5,13,11,6,9,14,6)

*Acoustic deformation potentials and heterostructure band offsets in semiconductors* Christensen-NE
CARDONA-M-1987-PHYS-REV-B-V35-P6182 300(7,37,35,36,25,27,25,26,25,18,21,11,7)

*Photoemision in solids. General Principles (Llibre)* CARDONA-M-1978-PHOTOEMISION-SOLIDS-V1
284(0,4,11,11,9,20,15,13,13,11,19,21,16,7,15,19,17,16,17,10,11,9)

*Chaotic motion and random matrix theories* Giannoni-MJ
BOHIGAS-O-1984-LECTURE-NOTES-PHYSIC-V209 282(2,3,10,20,14,20,21,24,20,25,33,29,19,18,17,7)

*Vibrational-spectra of Hydrogen in silicon and germanium*
CARDONA-M-1983-PHYS-STATUS-SOLI-B-V118-P463255(1,3,10,11,16,17,15,12,27,23,18,30,17,11,9,24,11)

*Desorption, Decomposition, and Deuterium-Exchange Reactions of Unsaturated-Hydroca..* Somorjal-GA
SALMERON-M-1982-J-PHYS-CHEM-US-V86-P341 220(3,12,12,15,22,7,22,14,19,10,11,12,12,9,14,7,11,8)

*Random matrix theories and chaotic dynamics* Giannoni-MJ
BOHIGAS-O-1991-LESHOUCHES-P87 212(1,6,23,29,35,41,36,26,15)

*Signals of a Phase-Transition in Nuclear Multifragmentation*
CAMPI-X-1988-PHYS-LETT-B-V208-P351172(0,9,12,6,26,19,21,23,18,17,10,11)

*Vibrational Modes of Hydrogen adsorbed on Pt (111):adsorption site and excitation mechanism*
BARO-AM-1979-SURFACE-SCI-V88-P384 155(0,7,11,13,12,11,15,8,6,18,9,6,5,4,4,4,7,5,5,2,3)

*Determination of Surface-Topography of Biological Specimens at High-res...*Garcia-N Miranda-R et alt
BARO-AM-1985-NATURE-V315-P253 153(3,14,15,23,25,23,17,12,4,7,2,3,2,3,0)

*Multifragmentation – Nuclei Break Up Like Percolation Clusters*
CAMPI-X-1986-J-PHYS-A-V19-P917 153(0,5,11,9,4,5,19,15,21,13,14,21,10,6)

*Relativistic band-structure and spin-orbita-splitting of zinc blonde-type semiconductors* Christensen-NE
CARDONA-M-1988-PHYS-REV-B-V38-P1806 147(0,7,23,12,7,18,20,14,21,9,12,5)

*Fluctuation properties of nuclear-energy Levels – Do Theory and Experiment Agree*Bohigas-O Pandey-A
HAQ-RU-1982-PHYS-REV-LETT-V48-P1086 144(1,4,5,7,7,7,12,13,7,9,10,9,7,11,8,10,6,10)

*Manifestations of Classical Phase-Space Structures in Quantum-Mechanics*Tomsovic-S Ullmo-D
BOHIGAS-O-1991-PHYS-REP-V223-P43 133(3,31,27,27,26,15,14)

*Aspects of Chaos in Nuclear-Physics* Bohigas-O Weidenmuller-HA
BOHIGAS-O-1988-ANN-REV-NUCL-PART-V38-P421 130(0,4,14,18,17,16,10,11,12,14,4,10)

*Nuclear Incompressibility – From Finite Nuclei to Nuclear-Matter* Bohigas-O Krivine-H Martorell-J
TREINER-J-1981-NUCL-PHYS-A-V371-P253 129(1,6,7,13,8,10,14,10,8,6,7,1,2,7,8,5,3,9,5)
*Thermal Evolution and Descomposition of Ethylene o Pt (111)*
BARO-AM-1981-J-CHEM-PHYS-V74-P4194 117(2,8,8,4,11,14,7,9,10,12,9,1,4,1,2,4,5,4,2)

*Lifetime of Particles Containing b Quarks.* Delfino-MC Desangro-R i altres
FERNANDEZ-E-1983-PHYS-REV-LETT-V51-P1022 110(0,0,0,2,49,27,20,2,2,0,1,2,1,2,0,1,1)

*X-ray analysis of the structural and dynamic properties of ...*Pernet-M Samaras-D Collomb-A Joubert-JC
OBRADORS-X-1985-J-SOLID-STATE-CHEM-V56-P171104(1,9,7,10,11,6,7,12,6,7,5,3,5,4)

*( ...) A signature of hard mass terms for a heavy top* Pich.
BERNABEU-J-1987-PHYS-LETT-B-V200-P569 102(1,1,0,9,7,14,22,25,7,7,9,0)

*The Preparation, Thermal-Stability and Adsorption Characteristics of the Non-Reconstruc...* Bonzel-HP
FERRER-S-1982-SURF-SCI-V119-P234 91(1,2,2,10,7,6,4,4,11,10,10,5,4,4,4,2,4,1)

*Imaging of Biomolecules with Scanning Tunneling...*Beebe-T Odriozola-J Wilson-T Ogletree-D Siekhaus-W
SALMERON-M-1990-J-VAC-SCI-TECHNOL-A-V8-P653 90(3,27,23,8,12,8,4,3,2,0)

*TITLE OTHER AUTHORS*
*TOTAL CITATION CODE* (Citations grouped by year, up to and including July 1999)

For reasons of space it was sometimes necessary to shorten the title and omit the names of some of the authors.

*Group1:*Crespo-JM Delfino-M Fernandez-E Martinez-M Miquel-R Mir-L Orteu-S Pacheco-A Perlas-JA Tubau-E
*Group2:* Alemany-R Crespo-JM Delfino-M Fernandez-E Gaitan-V Garrido-L Mir-LM Pacheco-A

Table 3. Distribution of articles most cited, by journals.

| *Journals* | *Catalan Institution* | *Non-Catalan Institution* |
|---|---|---|
| Phys. Lett. B (P) | 5 | 2 |
| Nuclear Phys. B (PN) | 4 | - |
| Nuov. Cim. B (P) | 3 | - |
| Phys. Rep. (P) | 2 | 1 |
| Acta Metall. (MS) | 2 | - |
| Phys. Rev. B (CM) | - | 4 |
| Phys. Rev. A (P) | 1 | - |
| Phys. Rev. D (PF) | 1 | - |
| Rep. Prog. Phys. (P) | 1 | - |
| Z. Phys. C (PF) | 1 | - |
| Lett. Nuov. Cim. (P) | 1 | - |
| J. Phys. A (P) | 1 | 1 |
| J. Appl. Phys. (AP) | 1 | - |
| Opt. Commun. (O) | 1 | - |
| Phys. Stat. Sol. (CM) | - | 1 |
| Nature (G) | - | 1 |
| J. Phys. Chem. (PC) | - | 1 |
| J. Chem. Phys. (PC) | - | 1 |
| Phys. Rev. Lett. (P) | 1 | 3 |
| Nucl. Phys. A (PN) | - | 1 |
| Surface Sci. (PC) | - | 2 |
| J. Solid State Chem. (PC) | - | 1 |
| J. Vac. Sci. Technol.(AP) | - | 1 |
| Solid State Commun. (CM) | 1 | - |
| Ann. Rev. Nucl. Part. (PN) | - | 1 |
| J.Opt.Soc.Am.B (O) | 1 | - |
| Books | 4 | 4 |

and the third the ones published by Catalan physicists working abroad. In brackets there is the scientific area of the journal according to the ISI classification for SCI (P: *Physics, general*; PN: *Physics, Nuclear*; PF: *Particles and Fields*; AP: *Applied Physics*; O: *Optics*; PC: *Physical-Chemistry*; CM: *Condensed Matter*).

The highest number of most cited papers is in the General Physics section. In fact it is a very heterogenous section, with some journals such as *Physics Letters B* that could be classified n the section Particles and Fields. Thus, high energy physics (theoretical and experimental) is the section in Catalonia with the highest rate of hot papers as a consequence of the intense efforts focused on this area since the middle 60's.

In particular, the main issues are high energy physics (theory; 9 papers), particle physics (experiment; 4 papers), statistical physics (7 papers), optics (7 papers), mathematics and physics (1 paper). The prominence of high energy physics is due to the tradition in this field initiated in 1965 through GIFT (inter-university theoretical physics group). These courses were long established afterwards at the IFAE (Institute of high energy physics), located at the UAB, but with the objective of stimulating the relationship between the UAB and UB research groups. This is a 30-year trajectory that has already yielded some results.

Statistical physics, the second field in number of highly cited papers, has undergone important growth since 1975: the most cited papers study stochastic processes, non-equilibrium thermodynamics, and phase transitions. It should be noted that the incentive role of the Statistical Mechanics School in Sitges, started in 1969 and still celebrated every two years, and the five sessions of the Thermodynamics School in Bellaterra between 1970 and 1990 were among other differentiated initiatives undertaken. Finally, in optics, five of the papers mentioned belong to the line of work related to laser and spectrography, and this has yielded some useful results for laser gas cooling. The other two works correspond to a very hot topic in nonlinear optics, namely, the observation of optical solitary waves in nonlinear media.

The panorama is totally different for the papers published by Catalan physicists abroad. Here, the main issues are nuclear physics (8 papers), condensed matter (4 papers about semiconductors and 3 about new surfaces) and tunnel effect microscopy (2 papers) and it is also clear that the absolute maximum in the number of citations is to be found in the authors that have worked abroad (especially in Germany, in semiconductors physics, and France, in nuclear physics). The coincidence of finding the proper line at the right time has provided a very high number of citations (over 650 in one paper, and over 500 in another one). The top citation reached by the authors in Catalonia is rather lower, almost 300 in one paper, which can be also considered a success.

The number of books (one of them is just a chapter) is also important. The ones contained in the first Table are dedicated to non-equilibrium thermodynamics, quantic cromodynamics, mathematical physics and a chapter on phase transitions. Of the books written abroad there is one about solids photoemission, another about chaotic movement and random matrix, as well as two chapters (located in different books) on this last issue.

Table 4. Percentage of articles cited more that 100 times respect to the total number of articles published, grouped by areas. The last column compares the impact indices of the different areas.

| | *Articles frequently cited* | *Total number of Catalan art. (1985-95)* | *% Impact by area* |
|---|---|---|---|
| Phys. (P) | 7 | 895 (0,8) | 3,20 |
| Phys. Part. Fields (PF) | 2 | 249 (0,8) | 3,06 |
| Phys. Nucl. (N) | 1 | 161 (0,6) | 3,25 |
| Phys. Cond. Matt. (CM) | 1 | 489 (0,2) | 2,83 |
| Appl. Phys. (AP) | 1 | 475 (0,2) | 1,64 |
| Optics (O) | 2 | 132 (0.6) | 1,19 |
| Material Sci. (MS) | 1 | 508 (0,2) | 2,05 |

## Distribution by SCI areas

The area distribution of bibliometric production yields important comparative possibilities at the international level. This distribution is based on the SCI classification (assigning journals to general epigraphs) and is presented in Table 4. In the second column we show the total number of papers published by Catalan universities in each area between 1985 and 1995, and in the third column the percentage for the considered period. The fourth column expresses the average value of the impact factor for journals contained in Table 3 in every area.

It is interesting to explore the number of hot papers in the whole production. For this analysis we have restricted the scope to papers published in Catalonia between 1985 and 1995. The total number of papers published for each area was presented in the *Report on Physics in Catalonia*, and is shown in the third column of Table 4. In the second column is the number of papers from table 1 corresponding to the previously mentioned period. The ratio between the values in the second column and the ones in the third appear in brackets in the third column and represent the percentage of papers cited over 100 times related to the total number of papers.

The resulting figures could be compared, with caution, to the data shown in *Current Contents*, extracted through a systematic search at world scale. As we show, (*Current Contents* of June 1984, volume 24) the number of papers cited over 50 times and 100 times was, respectively, 0,7% and 0,3% for the period 1961-1980. This average was referred to the whole of all scientific disciplines. If we take *Current Contents* of November 1983 (volume 23), the ratio of papers cited over 50 and 100 times for the period 1975-1979 was, respectively, 0,4% and 0,1%. Comparison of this data shows interesting and satisfactory achievements, especially for the *Physics* section (general physics) where the ratio is clearly higher than that indicated by the references in *Current Contents*.

The fourth column of Table 4 presents, for each area, the impact factor of the journals in Table 1. Its objective is to remind us that citation behaviour is different among different areas and it would be worth applying this correction factor to archieve an accurate thematic comparison. We observe that there are strong differences in the number of citation. Therefore we expect three times the number of citations for a *general physics* or *particle physics* paper than for an *optics* one (this takes into account the whole group of journals compared) and twice as many for an *applied physics* paper. Thus, the criterion used for selecting papers (obtaining the papers cited over 100 times) has to be taken with special caution. One should never use the list of hot papers automatically, without complementary comments.

## Time evolution

In Tables 1 and 2 we present the total number of citations and their thematic distribution. As expected, this presentation allows a better analysis of the different types of publications. Some examples are described below. Some papers go through a rather long stage of low citation until their thematic area becomes a hot area. This happened, for example, with the second and sixth papers of Table 1. These papers became highly cited when the methodology for cooling through laser beams started to achieve spectacular results, including a Nobel Prize. The concerned papers (plus 3 more papers in *optics* by the same group of authors) were, in a certain way, pioneers in this field and are now being cited after 15 years with just a few cites.

A different example can be observed from the papers related to the CERN experiments (e.g. the fifth paper of Table 1). In this case, the impact is immediate since there was much expectation for those results among the scientific community. The fast evolution of data, leads to a fall in citation after approx. 4 years. Still another situation is at represented by one of the papers on the observation of optical solitary waves. This has been cited more than 160 times in less than four years and still remains, for the moment, highly cited.

Other paper types, such as the *reviews*, maintain their influence longer until, usually, the same authors publish a new paper which becomes the new reference in the field. This is what happens with the *review* and with the thermodynamics book of Table 1.

The major factor that diminishes high citation rate is the

quick succession of new papers in one area. One paper may, for example, agglutinate a certain rate of citation for several years until the field shifts into new challenges. M.Rodríguez (1994) estimates that obsolescence in scientific bibliography for developed countries comes in approx. 8 years for the discipline of physics. In developmental countries, the citation period is longer and is affected by the local aspect of research. All these indications have to be taken into account when analysing increase and decrease in the citation rate of every single paper.

## Internationalisation

Another issue that could be considered in Table 1 is the degree of internationalisation of research in Catalonia. Seven of the 31 papers of the afore mentioned table have been authored only by Catalan researchers whereas the others have been undertaken in collaboration scientist from other countries. Obviously, these 7 papers are no less international in impact than the others and might be the consequence of prior collaborations.

It would be of interest to explore whether the impulse behind the papers originated with the Catalan researchers or by contrast, their participation was passive, enjoying the benefits of an influential international group. This would, however, require more information to work in depth and it exceeds the scope of this study.

Another aspect concerning collaborating countries is that most of them are European. Only in 7 papers are collaborators American whereas they are European in 24 publications. In Table 2, where we can see the output of Catalan researchers working abroad, European destinations (France and Germany) dominate over the United States. This last consideration includes Catalan scientists in other Spanish universities.

## Conclusions

At a time when scientists are under pressure to publish, the number of papers is becoming a far less suitable measure of real quality of research in one country. Nevertheless, this indicator can be complemented by the analysis of bibliometric impact.

Researchers should assume that the publication of a paper does not represent the final stage of their research since considerable efforts to disseminate the results should be made in to order to enhance the impact this, we feel, is an attractive indicator for research evaluation. Moreover, it is common that one paper will be used as a reference for another scientific field and this fact could strongly motivate the original authors of the publication.

This paper considers the important role of collaborations within Europe more than anywhere else. On the other hand, it shows a considerable concentration of papers in certain areas, classified by groups and authors. It is interesting to note that, *nuclear physics and random matrix* achieve 5 papers; *laser and optic pumping*, also 5 papers; *optic effects and acoustics in semiconductors*, 4 papers; experiments at *CERN (LEP*), 4 papers; *irreversible thermodynamic processes*, 3 papers; *observation of spatial solitary waves in optics,* 3 papers; etc. This effect is quite ubiquitous in the bibliographic references where citation is mainly collected in certain well defined issues, changing with time.

We have tried to avoid very detailed comparisons which could lead to negative competition between research groups. The aim of our paper was mainly the collection of data to estimate the quality of Catalan physics. Thus, in the first section of this study we have highlighted the caution that should be exercised when citation analysis is developed. Certain very valuable emerging lines, might be a hidden cause of the dispersion in multiple papers. This would mean that they would not have reached the minimum of 100 cites in at least one paper.

This analysis proves that the relative number of papers cited over 100 times is satisfactory, and this indicator oscillates a bit over the international average, as we can see in the processed data. Then it seems that the improvement in supporting research translates into good results, at least for this special aspect of research. In the near future we shall process in detail other bibliographic data concerning the average impact of the papers with the aim of enhancing knowledge of the Physicists' community, in terms of their common results and achievements.

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